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E. V. Lapayev, O. A. Vorob'yev and V. V. Ivanov

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16. Abstract
It was revealed that during the tests with continuous action of sign-variable Coriolis acceleration the development of kinetosis was proportionate to the time of head inclinations in the range of 1 to 4 seconds while illusions of rocking in sagittal plane was more expressed in fast inclinations. The obtained data provided the evidence of sufficient dependence of vestibulovegetative and vestibulosensory reactions on the period of repetition of sign-variable Coriolis acceleration.

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DEPENDENCE OF VESTIBULAR REACTIONS ON FREQUENCY OF ACTION OF SIGN-VARIABLE ACCELERATIONS

E. V. Lapayev, O. A. Vorob'yev and V. V. Ivanov

It is known that Coriolis accelerations that develop when man /33* moves in various (aviation, space, etc.) technical rotating systems at an angle to the rotation axis are adequate stimuli of the vestibular analyzer, and cause pronounced vestibular reactions (V. I. Voyachek, 1908; K. L. Khilov, 1952; Schubert, 1954; and others). Therefore methods are currently widspread in the practice of vestibular selection, consultation and training that employ prolonged, cumulative effects on the organism of sign-variable Coriolis accelerations (I. I. Bryanov, 1963; S. S. Markaryan et al., 1966; A. S. Kiselev, 1968; Dowd, 1973; and others). /34

These effects are simulated under laboratory conditions during man's rotation around a vertical axis and incline of the head or the torso in the frontal or sagittal planes. It has been established that with a rotation velocity of 60°/s and frequency of head inclines 0.25 Hz, in the majority of cases no pronounced motion sickness develops, while the effect of Coriolis accelerations with rotation velocity of 180°/s and analogous frequency of inclines causes considerable vestibular reactions (I. A. Sidel'nikov, 1970). Miller and Graybiel (1970) showed that an increase in the rate of chair rotation causes pronounced motion sickness under the influence of Coriolis accelerations with a smaller number of inclines of the head and torso.

*Numbers in margin indicate pagination in original text.

The presented facts indicate that the rapid development of vestibular reactions during the effect of Coriolis acclerations significantly depends on the intensity of horizontal rotation. In this respect it was important to study the dependence of pronounced vestibulo-autonomic reactions on the frequency of head inclines with unchanged chair rotation velocity. There is only spotty information about this in the literature, that mainly covers a single effect of Coriolis accelerations (G. A. Arustamov, 1964; K. L. Khilov, 1969). This work set the goal of studying the effect of varying velocity (frequency) of head inclines on the rapidity and pronounced nature of development of vestibulo-autonomic reactions of the body during the prolonged, cumulative effect of Coriolis accelerations.

Four series of experiments were carried out with the participation of 26 healthy men in age from 21 to 45. The studies were made on an electrically rotating chair. The rotation of the subjects in all series of studies was at a velocity of 180°/s, while the head was tilted in the frontal plane at a 30° angle to each side. The time for the movement of the head from one extreme lateral position to the other (i.e., the half period of oscillating movement) in the I series equalled 1 s, in the II series it was 2 s (as is now accepted in this type of test) in the III series 4 s, and in the IV series 8 s. The velocity of executing the inclines was assigned with the help of an electronic metronome, and their amplitude was recorded by limiters installed on the right and left. The inclines were made smoothly and continuously, without delays in the extreme and middle positions. Before the beginning of the study each subject was instructed on the need to report to the experimenting physician any changes in his state of health during the experiment. The endurance of the test, and consequently, the vestibulo-autonomic stability of the body was evaluated by the time from the beginning of head rocking to the appearance in the subject of a pronounced feeling of nausea as the control symptom. Other subjective and objective autonomic reactions were recorded here, as well as the latent period for the occurrence of vestibulo-sensory sensations--

the illusion of rocking. If no vestibulo-autonomic symptoms appeared in the subject, then the effect was continued for no more than 15 min. The experiments were carried out at the same time of day, but no less often than in 4-6 days.

The results of the conducted studies demonstrated that in the I series the time for endurance of the cumulative effect of Coriolis accelerations was on the average 13.4±0.5 min. In the II series of experiments, the endurance was statistically reliably lower ($P<0.01$) than in the I series, 8.1±0.7 min., but significantly ($P<0.01$) greater than in the III series, where the endurance time of this test equalled 3.5±0.4 min. And finally, in the IV series the endurance of Coriolis accelerations equalled 3.1±0.3 min, which practically did not differ from the results of the III series ($P>0.05$) and was statistically reliably lower than the data of the I and II series ($P<0.01$). Consequently, of the four modifications of employed effects the first was endured the most easily (i.e., the vestibulo-autonomic symptoms developed considerably later); here the rate of head inclines was the greatest. Analysis of the findings demonstrates that as the rate (frequency) of head inclines drops there is a reduction in the endurance of the Coriolis acceleration test, i.e., pronounced vestibulo-autonomic disorders develop faster. /35 However, it needs to be noted that such a law is noted only in a certain range of head movement velocities. Thus, with an increase in the time of incline above 4 s the vestibulo-autonomic resistance to the effect of Coriolis accelerations is not significantly altered.

With different patterns of accleration effect, not only the rate of development of the symptoms complex of motion sickness, but the nature of vestibulo-autonomic symptoms were not the same. Thus, with rapid rocking of the head, the autonomic symptoms developed gradually, and at the first stages of effect, in the words of the subjects, they were not unpleasant. Initially a sensation of warmth developed in the entire body (as in moderate physical work), then hyperhidrosis in the region of the face, back, etc.; after this, pronounced nausea appeared only in certain individuals. With slow

rocking the symptoms of motion sickness developed quickly, and starting from the first moments of the effect, they were subjectively very unpleasant. It should be noted that in the given case, in the beginning heaviness in the head developed that often became a headache. Further a sensation of heaviness appeared, a dull pain in the entire body, chill, cold sweat and nausea that was difficult to contain (rapidly increasing). Only certain individuals endured the entire 15 minute effect of Coriolis accelerations with slow rocking of the head without a pronounced feeling of nausea. In addition, one should stress the fact that with slow rocking of the head, as a rule, no distinct illusion of rocking was noted in the sagittal plane, and its amplitude was considerably lower than with rapid rocking, when such an illusory sensation was noted fairly distinctly by the subjects.

Thus, the findings indicate the significant dependence of pronounced vestibulo-autonomic and vestibulo-sensory reactions on the rate of head inclines during double rotation.

It should be indicated that F. A. Solodovnik (1974) in certain different conditions, with rotation in a chair and inclines of the head in the frontal plane with 5-second delays in the extreme positions, also found a reduction in the vestibulo-autonomic resistance and the absence of an integral illusory sensation of rocking as compared to the continuous rockings of the head. It is known that the degree of pronounced somatic reactions to the effect of Coriolis accelerations also depends on the rate of straightening the torso and the head: the faster this movement is made, the more distinctly the reaction appears, and vice versa, with a very slow straightening reaction it can also not appear (K. L. Khilov, 1969).

Thus, a direct dependence was recorded of the pronounced nature of the sensory and somatic reactions on the frequency of action of sign-variable Coriolis accelerations, and an inverse dependence--for the vestibulo-autonomic reactions.

We will examine the possible mechanisms for the obtained experimental data. When a physical model of the vestibular apparatus is used, it has been shown that unequivalent shifts occur in the vestibular receptors in opposite directions, that govern the non-sinusoidal movements of the cupulae and otoliths during sinusoidal oscillations of the head (S. V. Petukhov, 1973). As a result of this, a constant component is accumulated for deviation of the vestibular receptors in relation to the position of rest, i.e., differential deviation of the receptors develops. Consequently, one can hypothesize that the insignificant pronounced nature of the vestibulo-sensory and vestibulomotor reactions with low frequencies of head rocking is governed by the small differential /36 deviations in the vestibular receptors. With a rise in the frequency of head inclines the differential deviation of the receptor structures is increased, which also entails great pronouncement of the indicated reactions.

An increase in the rate of development of motion sickness as the frequency of head inclines drops can be partially explained by the peculiarities in the dynamic characteristics of the vestibular receptors. As is known, the mechanical (dynamic) characteristics of the vestibular receptors are described well with the help of the model of twisting pendulum with great friction (A. N. Razumeyev, A. A. Shipov, 1969; Steinhausen, 1933; and others). This model, as L. R. Yang indicates (1970), for very low frequencies of oscillating movement (less than 0.19-0.1 rad/s) predicts the greater delay in the reaction phase than for the medium frequency range (0.1-2.0 rad/s). As a consequence of the increase in the reaction phase delay at low frequencies there is an apparent increase in the conflict of the information coming from the otoliths and the semicircular canals, which is viewed as one of the reasons for motion sickness (Guedry, 1968). In addition, one cannot completely exclude that fact that during great frequency of the head inclines the weak appearance of the vestibulo-autonomic reactions can be governed by reciprocal inhibition of their pronounced nature by the vestibulo-sensory and vestibulo-somatic reactions.

In the studies that cover a study of motion sickness during vertical movements, the dependence of the rate of development of vestibulo-autonomic disorders on the frequency characteristics of the effect has been noted many times (A. I. Vozhzhova and R. A. Okunev, 1964; Alexander et al., 1947). It has been indicated that motion sickness causes sign-variable accelerations in the vertical plane with frequency of repetition no more than 0.5 Hz (Kennedy et al., 1972; O'Hanlon and McCauley, 1974).

In our studies the most pronounced vestibulo-autonomic disorders developed during the effect of sign-variable Coriolis accelerations 0.125 and 0.063 Hz, and the least pronounced--with frequency of 0.5 Hz. Consequently, one can speak of a certain coincidence of the frequency ranges of the sign-variable linear accelerations (directed vertically) and Coriolis accelerations that induce the maximum vestibulo-autonomic disorders. However, in relation to the Coriolis accelerations the maximum effect is observed at lower frequencies of effect. The latter circumstance is most likely linked to the fact that the linear accelerations are primary stimulants of the otolithic receptors, while the Coriolis accelerations have a complex effect on both the otoliths and the semicircular canals. The cupulo-endolympathic system possesses, as is known, more significant damping properties,(i.e., is inertial to a greater degree) than the otholithic receptors. Therefore, an increase in the lag of the reaction phase of the semicircular canals occurs at lower frequencies of the oscillating head movements.

Thus, as a result of these studies we revealed the dependence of the vestibulo-autonomic and vestibulo-sensory reactions on the frequency of action of the sign-variable Coriolis accelerations. This fact can be used in searching for the optimal characteristics for stimulating the vestibular analyzer for purposes of vestibular selection and training, as well as in the further study of mechanisms for motion sickness.

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